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Adams

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[54] **RECIPROCATING SYSTEM**

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[51] **Int. Cl.**[6] **F02B 71/00**

[52] **U.S. Cl.** .... **123/46 R**

[58] **Field of Search** .... 123/46 R, 46 SC; 417/364, 380, 11, 342

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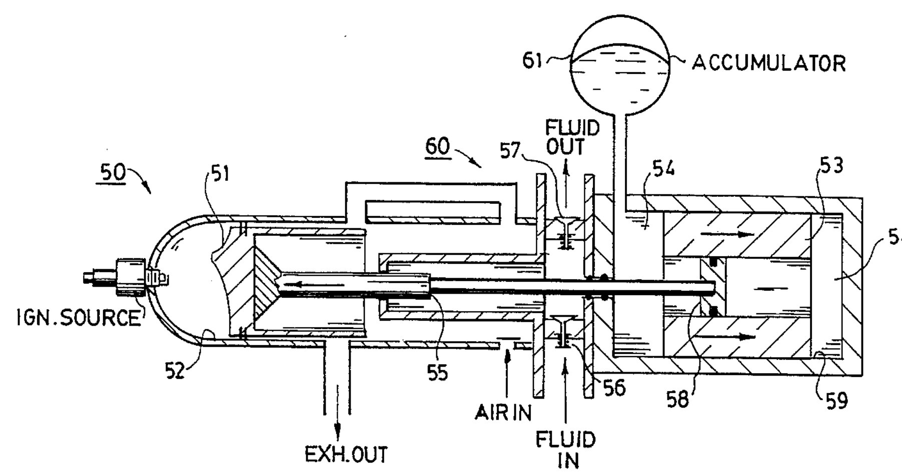
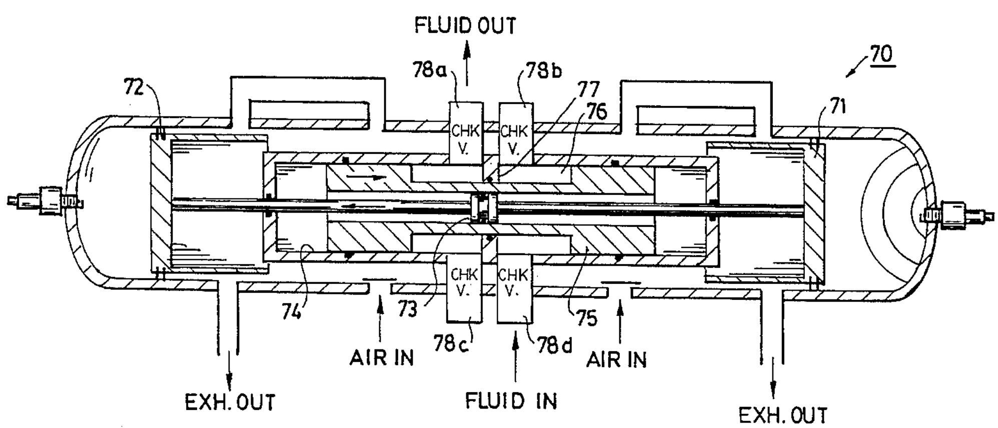
Primary Examiner—David A. Okonsky
Attorney, Agent, or Firm—Eugene Stevens & Associates

[57] **ABSTRACT**

Three elements are hydraulically coupled by a hydraulic fluid contained within one of the elements serving as a housing so that reciprocally driven motion of one of the elements is transmitted to move another element responsively in a reciprocal motion. The movements can be counter-reciprocal or co-reciprocal, and the housing can be an unmoved element or can be one of the reciprocally moving elements. The stroke lengths and velocities of the reciprocal movements can vary, and the effect can involve dynamic balance, power transformation, vibrational dampening, and many variations of these possibilities.

45 Claims, 6 Drawing Sheets





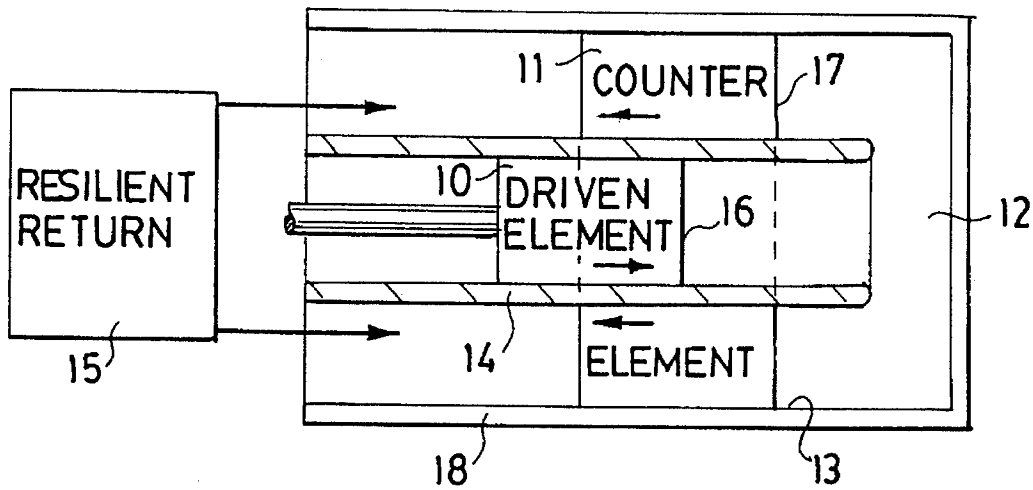

RESILIENT RETURN
15
11
COUNTER
17
10
DRIVEN ELEMENT
16
12
14
ELEMENT
18
13

FIG. 1

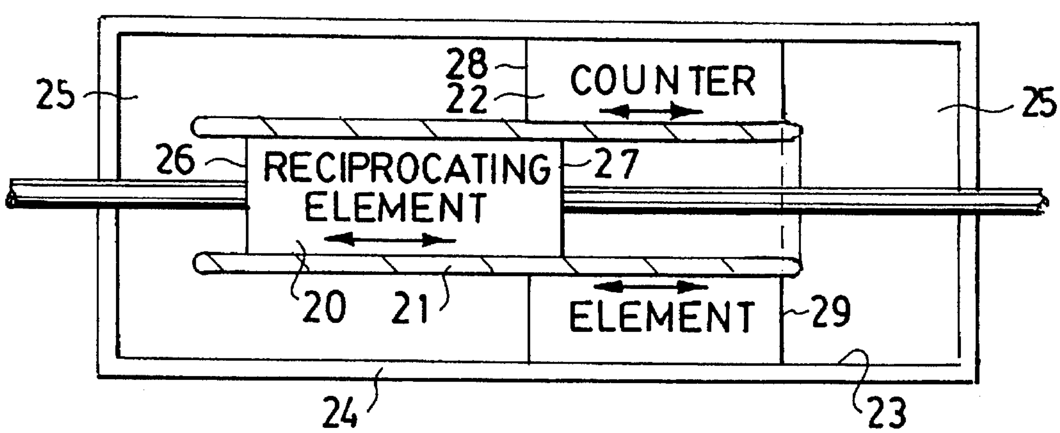

25
28
22
COUNTER
25
26
RECIPROCATING ELEMENT
27
20
21
ELEMENT
29
24
23

FIG. 2

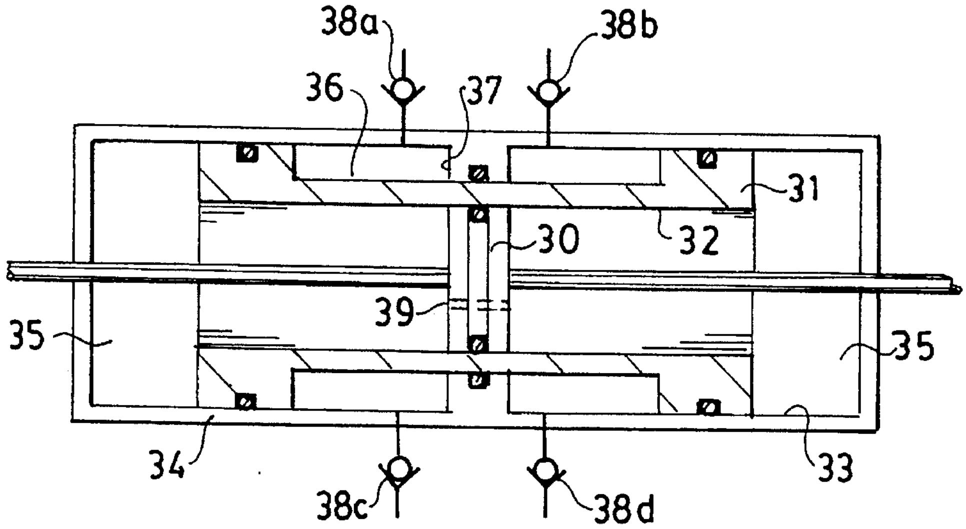

38a
38b
36
37
31
30
32
39
35
35
34
33
38c
38d

FIG. 3

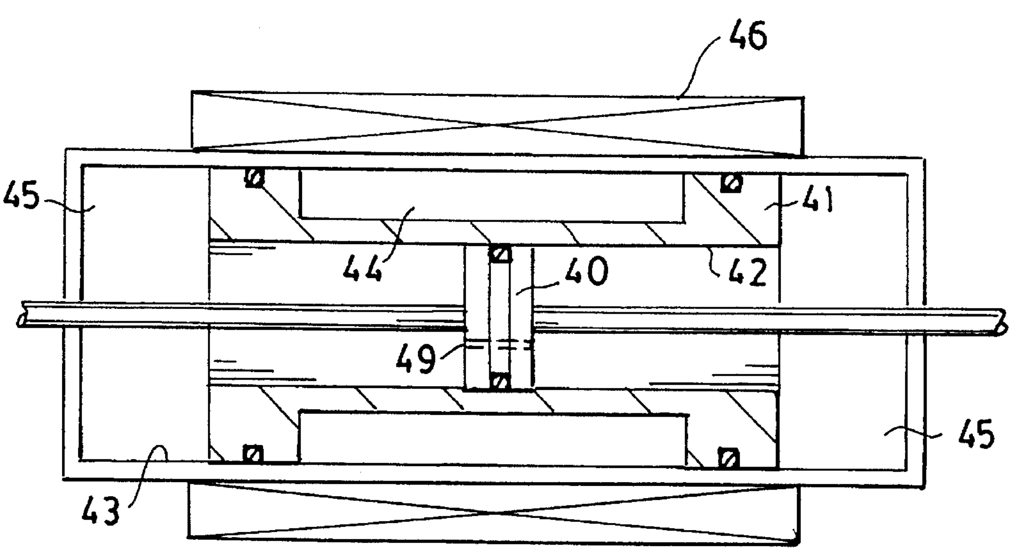

46
45
41
44
40
42
49
45
43

FIG. 4

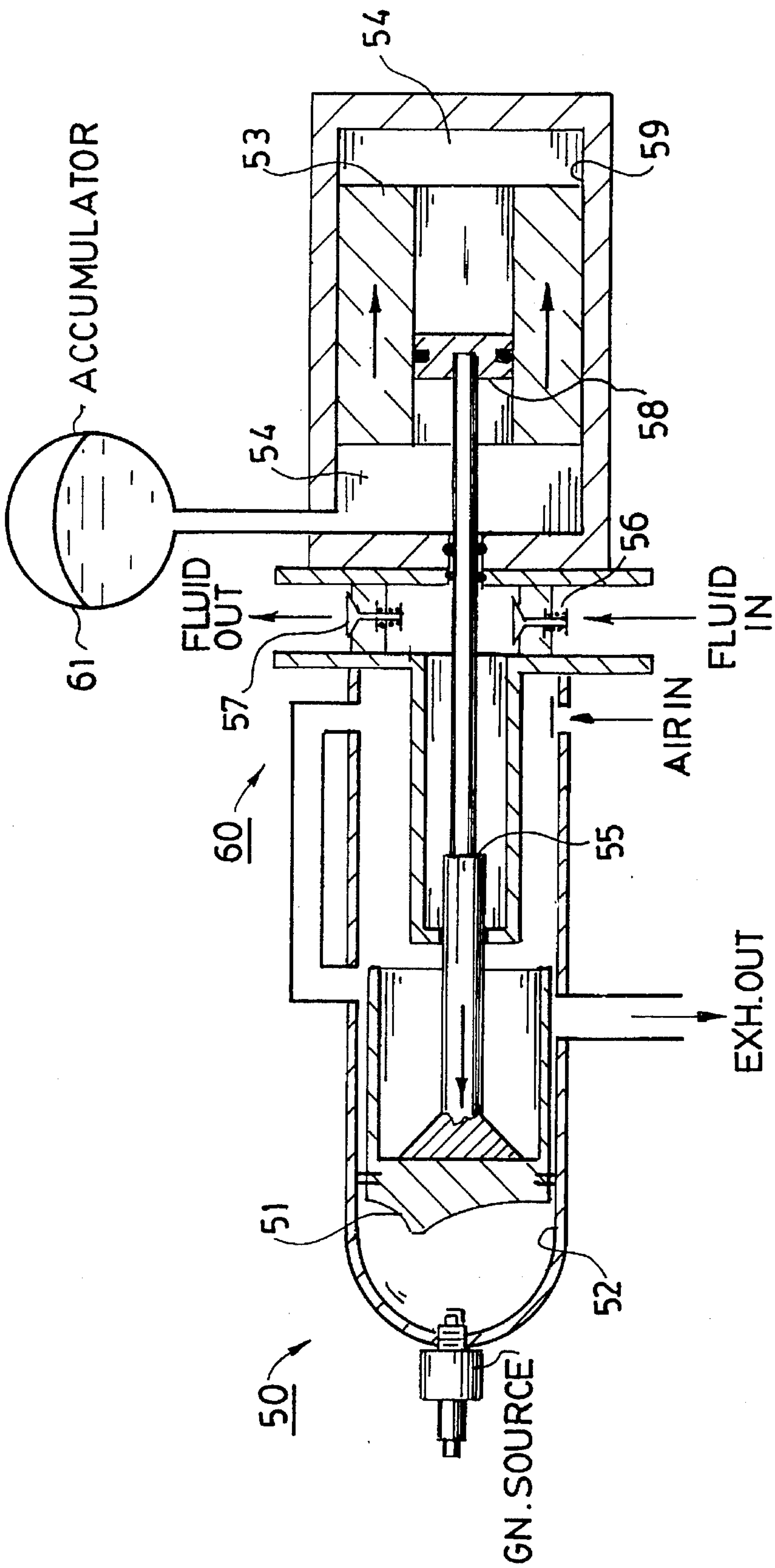

ACCUMULATOR
54
53
59
58
54
56
61
FLUID OUT
FLUID IN
57
AIR IN
60
55
EXH.OUT
51
52
50
IGN. SOURCE

FIG. 5

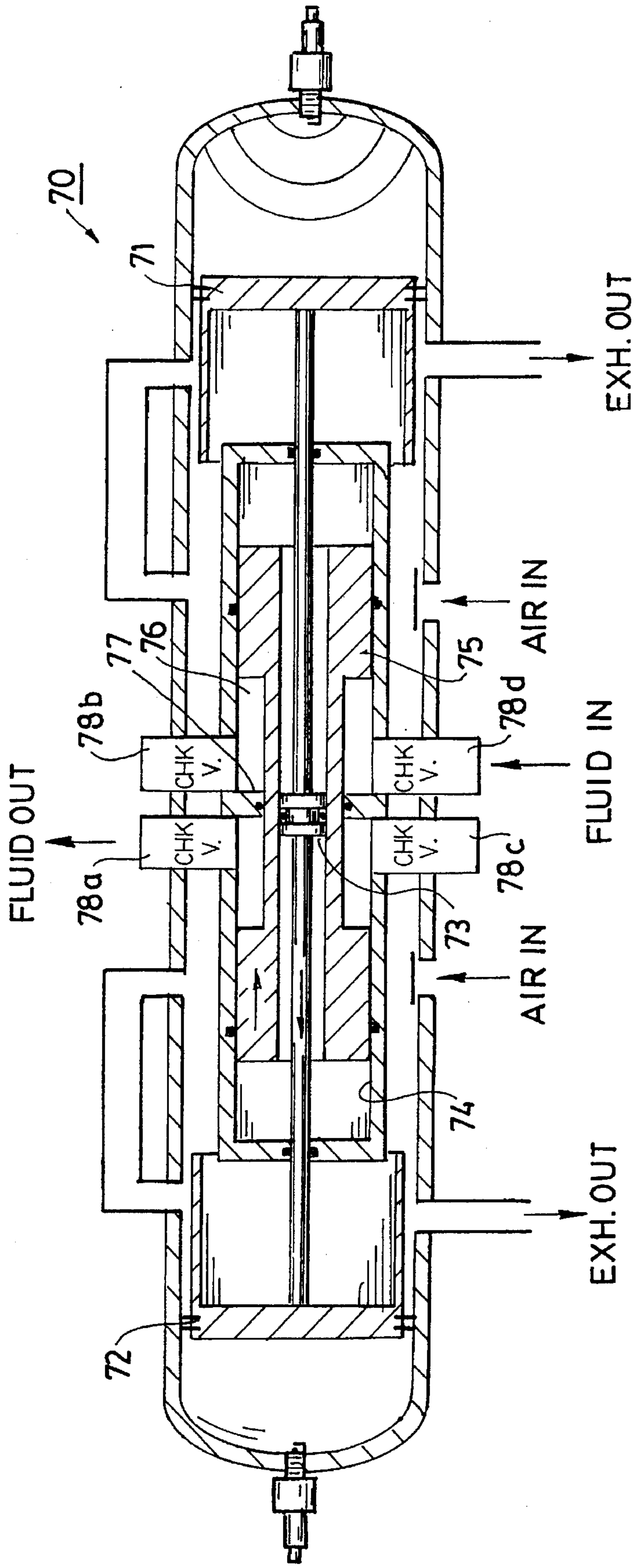

70
71
EXH. OUT
AIR IN
75
76
77
78b
78d
CHK V.
FLUID IN
FLUID OUT
78a
78c
73
AIR IN
74
EXH. OUT
72

FIG.6

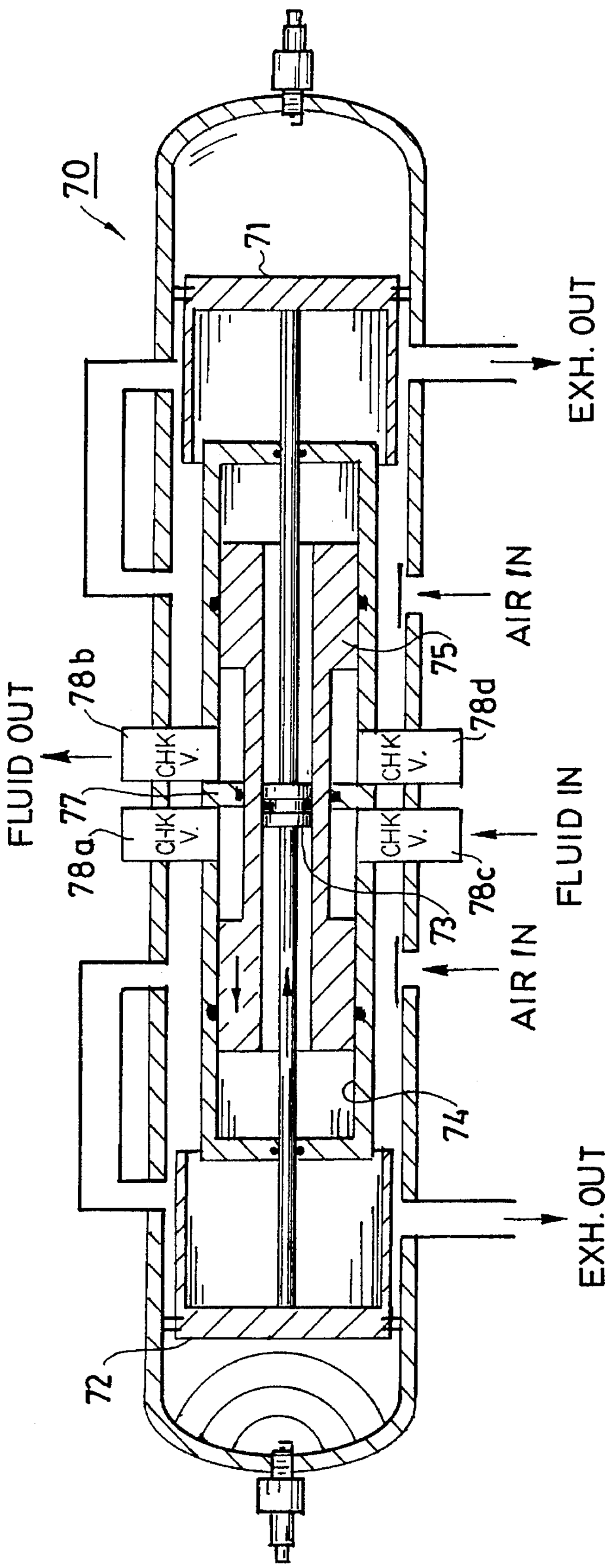

70
71
EXH. OUT
AIR IN
75
78b
78d
FLUID OUT
CHK V.
CHK V.
77
CHK V.
CHK V.
FLUID IN
78a
78c
73
AIR IN
74
EXH. OUT
72

FIG. 7

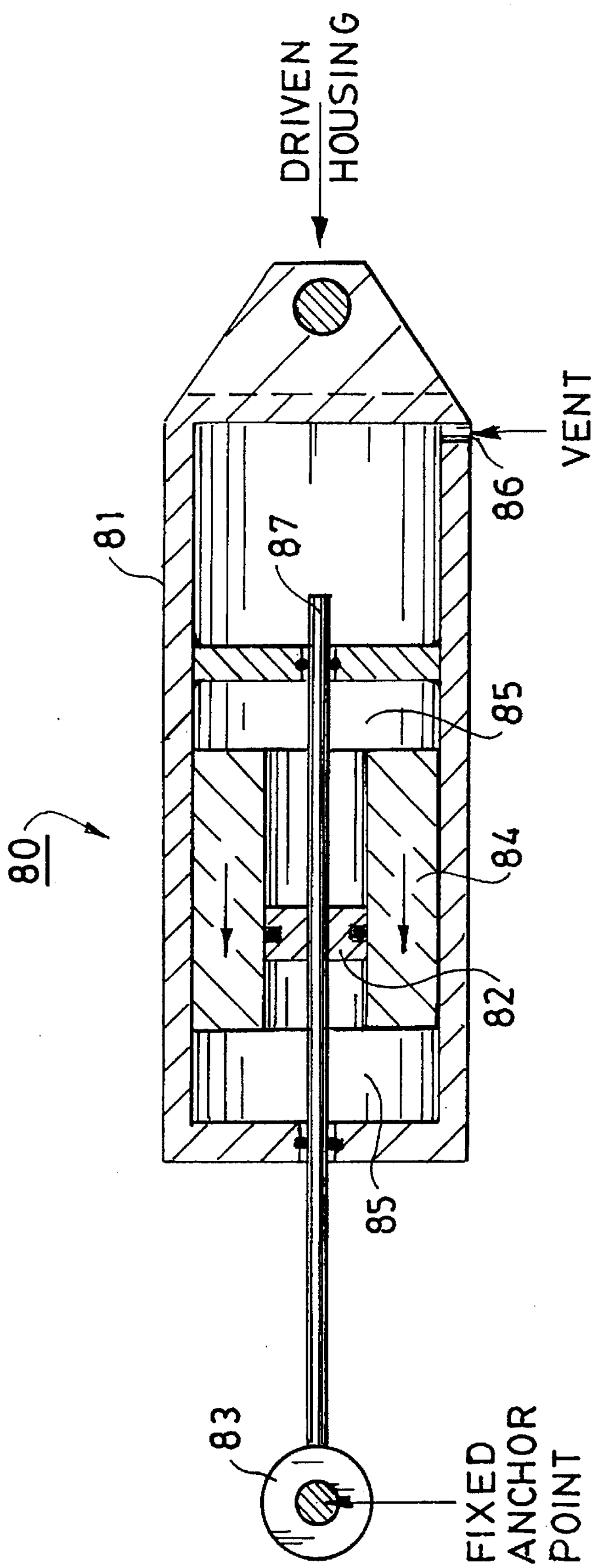

DRIVEN HOUSING
VENT
86
87
81
85
80
84
82
85
83
FIXED ANCHOR POINT

FIG.8

RECIPROCATING SYSTEM

FIELD OF THE INVENTION

This invention involves reciprocating elements, at least one of which receives a power input.

BACKGROUND

This invention arose from a need to improve the dynamic balance of a reciprocating system. In meeting this need, I have intercoupled reciprocating elements in a new way that leads to several advantages. My coupling of reciprocating elements is not only fast, efficient, and reliable, but is easily varied to produce different effects, such as dynamic balance, shock absorption, and power input and output functions. These advantages allow my reciprocating system to outperform previous arrangements.

SUMMARY OF THE INVENTION

My system for coupling reciprocating elements uses hydraulic fluid communicating with a pair of reciprocating elements so that movement forced upon one of the reciprocating elements is transferred hydraulically to move the other element in the same or an opposite direction. The resulting reciprocating movements can be parallel or coaxial, and can involve sliding contact or separated paths. The hydraulic fluid coupling can be applied to one or both end regions of the reciprocating movements, and elements hydraulically coupled for counter- or co-reciprocating movement can be applied to an infinite variety of functions in engines and machines. Power can be input to either reciprocating element, making hydraulically transmitted movement of the other reciprocating element responsive; and the responsive element can be involved in power output. A housing holding the hydraulic coupling can be one of the reciprocating elements while containing another of the reciprocating elements. The stroke lengths, velocities, and masses of the reciprocating elements can be varied to transfer momentum from one to the other in different regions of the respective movement strokes, for tuning the relationship between the moving elements.

DRAWINGS

FIG. **1** is a schematic view of a simple form of my reciprocating system using a resilient return.

FIG. **2** is a schematic diagram of another embodiment of my reciprocating system applied to an element driven in opposite directions.

FIG. **3** is a schematic diagram of my reciprocating system producing a pumped output from a responsively-reciprocating element.

FIG. **4** is a schematic diagram of my counter-reciprocating system producing an electrical output from a counter-reciprocating element.

FIG. **5** is a partially schematic, cut-away view of a linear internal combustion engine operating a pump and provided with a counter-reciprocating element and return mechanism according to the invention.

FIGS. **6** and **7** are partially schematic, cut-away views of an opposed piston linear engine with a counter-reciprocating element serving as a pump—a stroke in one direction being illustrated in FIG. **6**, and a stroke in an opposite direction being illustrated in FIG. **7**.

FIG. **8** is a partially schematic diagram of a reciprocating system involving reciprocal movement of a housing.

DETAILED DESCRIPTION

My system involves three interconnected elements at least two of which are movable reciprocally. A driven one of these receives the power input, and a responsive one can be involved in dynamic balance, power output, or other purposes. A hydraulic coupling involving hydraulic fluid communicates between the elements so that motion of the driven element is transmitted hydraulically to the responsive element. The hydraulic fluid is preferably contained within a housing that can constitute one of the elements. The housing can be moved or unmoved, as can the other two elements. The reciprocal motions can be counter-reciprocal or co-reciprocal, and the hydraulic coupling allows variation in stroke lengths and speeds of the movements. A few of the many applications of my invention are illustrated in the drawings.

A simple arrangement of a counter-reciprocating system is shown in FIG. **1** where motion of a driven element **10** is transmitted to a counter element **11** moving in an opposite direction. Both elements are arranged in communication with a hydraulic fluid **12** confined within a chamber **13** of an unmoved housing **18** so that movement of the driven element **10** to the right, as indicated by the arrow in FIG. **1**, moves counter element **11** to the left, as indicated by the arrows in FIG. **1**. Elements **10** and **11** are arranged to move co-axially of each other and can be separated by wall **14**. The counter-reciprocating elements can also move in parallel with each other, preferably with one of the elements arranged to straddle the other. In the arrangement of FIG. **1**, driven element **10** is a cylindrical piston moving reciprocally within wall **14**, and counter element **11** is an annular element moving outside of wall **14** within chamber **13**.

A resilient return **15** biases counter element **11** leftward against the direction of the arrows as shown in FIG. **1**. This returns counter element **11** toward the right side of chamber **13** and moves driven element **10** leftward within wall **14**. Resilient return **15** can be a spring or a volume of compressed air, acting against counter element **11** either directly or via a hydraulic system having an accumulator. A resilient return **15** can also be applied in an opposite direction to driven element **10**.

Hydraulic fluid **12**, which is confined in chamber **13**, communicates with a working surface **16** of driven element **10** and with a working surface **17** of counter element **11**. Working surfaces **16** and **17** can be varied in area, which changes the stroke length and velocity of counter element **11** relative to driven element **10**. Any edges or corners of surfaces engaged by hydraulic fluid **12** are preferably rounded to minimize turbulence in hydraulic fluid **12**, which changes shape as the counter-reciprocating strokes of elements **10** and **11** occur.

The counter-reciprocating elements **10** and **11** can have equal or unequal masses and still achieve the advantage of a counterbalancing effect. Making masses, stroke lengths, and velocities equal for elements **10** and **11** is one way of accomplishing this, but unequal masses can still have a counterbalancing effect if the stroke length and velocity of the smaller mass is made larger than the stroke length and velocity of the larger mass. The hydraulic intercoupling of elements **10** and **11** makes stroke length and velocity relationships easy to change by changing the size of the hydraulic working surfaces of the two elements.

Unequal masses can serve other purposes, though, since the division of momentum between the two elements and the transfer of momentum from one element to another at different periods of their reciprocating strokes can beneficially influence the way power is input or output. This can be useful in many applications, but one important application where it affords an advantage is in tuning the movement and timing of a two-stroke engine piston driving one of the reciprocating elements. Momentum can be transferred from the driven piston to the counter element during an early portion of the power stroke, when the piston is being accelerated by combustion forces. Then at the exhaust end of the piston travel, where it is desirable for the piston to dwell long enough to satisfy exhaust and intake requirements, the counter element can transfer momentum back to the piston.

The counter-reciprocating System of FIG. **2** does not use any resilient return. It includes an element **20** that is reciprocally driven within a cylinder **21** and is countered by an element **22** moving outside of cylinder **21** and within chamber **23** of unmoved housing **24**. The hydraulic coupling between elements **20** and **22** includes hydraulic fluid **25** that fills chamber **23** and engages working surfaces on both ends of each counter-reciprocating element. For driven element **20**, these working surfaces are **26** and **27**; and for responsive element **22**, the working surfaces are **28** and **29**. The reciprocal movement of element **20** can be provided by opposed pistons or other opposed drivers or can result from a drive motion in one direction and a resilient return motion in the opposite direction. Movement of element **20** in either direction causes counter movement of element **22** in an opposite direction because of the hydraulic interconnection via working surfaces **26–29**.

The counter-reciprocating system of FIG. **3** includes a reciprocating piston **30** and a Counter-reciprocating element **31** arranged to operate as a fluid pump. Driven piston **30** moves within a bore **32** of element **31**, and both elements are arranged within a chamber **33** of a housing **34** where they are hydraulically coupled by a fluid **35**. Movement of piston **30** in one direction hydraulically moves counter element **31** in an opposite direction, to achieve counter-reciprocating movements. Piston **30** can be driven back and forth in many ways, by many sources of power.

Hydraulic fluid **35** is divided into two volumes arranged on opposite sides of piston **30** and counter element **31**. This disposes hydraulic fluid **35** at the end regions of the reciprocating strokes of each element. A bleed passageway **39** formed through piston **30** ensures that hydraulic pressures remain approximately equal at opposite ends of chamber **33**, which automatically centers counter element **31** within chamber **33**. Any eccentric positioning of counter element **31** and hydraulic fluid **35** would cause more pressure at one of the end regions of each of the counter-reciprocating strokes, and a hydraulic bleed passageway **39** prevents such a pressure build-up by equalizing the hydraulic end pressures, which in turn centers counter element **31** within chamber **33**.

Counter element **31** has an annular cavity **36** that is divided into two parts by chamber wall **37**. Each cavity part is connected to pumped fluid lines by check valves **38***a–d*. As counter element **31** moves back and forth in counter-reciprocal movement relative to piston **30**, the divided portions of cavity **36** become larger and smaller, allowing element **31** to act as a pump in cooperation with check valves **38**. As element **31** moves to the right, as shown in FIG. **3**, a pumped outflow occurs through check valve **38***a* and an inflow occurs through check valve **38***d*. As element **31** moves leftward, as viewed in FIG. **3**, a pumped outflow occurs through check valve **38***b*, and an inflow occurs through check valve **38***c*. These flows can be combined to form a pumped stream of fluid as element **31** reciprocates. Not only does element **31** have a counterbalancing effect relative to the mass that reciprocates with piston **30**, but element **31** also outputs power in a different form than is input to piston **30**.

The counter-reciprocating system of FIG. **4** is similar to the arrangement of FIG. **3**, in using a reciprocating piston **40** and a counter-reciprocating element **41**, but differs in the way that element **41** is involved in a power output. Element **41** contains a magnet **44** that reciprocates within an electric coil **46** wound around chamber **43** to produce an electric power output. Magnet **44** can be divided into many magnets, and coil **46** is oriented so that reciprocal movement of element **41** produces an electrical output. Otherwise, piston **40** moves reciprocally within bore **42** of element **41**, and the motion of piston **40** is hydraulically transmitted to element **41** by hydraulic fluid **45** so that elements **40** and **41** move counter-reciprocally.

In either of the embodiments of FIGS. **3** and **4**, the power transfer produced by counter element **31** or **41** can be converted to a power input that moves element **31** or **41** reciprocally to cause a counter-reciprocal movement of piston **30** or **40**. This can be used for many purposes, including starting an internal combustion engine having a combustion piston connected with piston **30** or **40**. Generally, power input can be supplied to either of the counter-reciprocating elements, for hydraulically driving the other element counter-reciprocally in response.

The counter-reciprocating system of FIG. **5** is similar to the one shown in FIG. **1** and illustrates application of the system to a two-stroke linear engine **50** driving a pump **60**. Combustion piston **51** moves reciprocally within cylinder **52** and drives a linearly reciprocal piston **55** of pump **60**. Check valves **56** and **57** cause pumped fluid flow as piston **55** reciprocates. A counter element **53** is hydraulically coupled to reciprocally driven piston **58** by hydraulic fluid **54** so that counter element **53** moves counter-reciprocally to pistons **58**, **55**, and **51**. The return stroke for all these pistons is provided by hydraulic accumulator **61** acting on hydraulic fluid **54** to drive element **53** in the direction of the arrows. This moves pistons **58**, **55**, and **51** leftward as indicated by the arrow in FIG. **5**. The opposite reciprocal motions occur on a power stroke driving piston **51** toward the right as viewed in FIG. **5**.

The counter-reciprocating system of FIGS. **6** and **7** provides a pumped output for an opposed twin cylinder, two-stroke engine **70**. Combustion pistons **71** and **72** are driven reciprocally within engine **70**, which reciprocates piston **73** within chamber **74** where counter element **75** moves counter-reciprocally. A cavity **76** in element **75** is divided by a wall **77**, and check valves **78***a–d* are arranged so that changes in cavity sizes on opposite sides of wall **77** serve as a fluid pump. On a leftward stroke of combustion pistons **71** and **72**, as illustrated in FIG. **6**, pumped fluid is drawn in through check valve **78***d* and is pumped out through check valve **78***a*. On a rightward stroke, as illustrated in FIG. **7**, pumped fluid is drawn in through check valve **78***c* and is pumped out through check valve **78***b*.

Co-reciprocal movement of elements is also possible, especially when a housing containing the hydraulic fluid coupling is one of the reciprocating elements. This is possible since any system according to my invention involves three elements, two of which reciprocate, and one of which is unmoved; and the housing containing the fluid coupling can function as either a moving or an unmoved element, depending on the goal that is sought. The unmoved element need not necessarily be fixed or held in an immovable position, but it need not participate in the reciprocal motions of either the driven or responsive elements.

Device **80** of FIG. **8** represents a co-reciprocal motion involving a housing **81** that serves as the driven reciprocal element. The unmoved element is piston **82** that is anchored at a fixed point **83**. The responsively reciprocating element **84** is hydraulically coupled to piston **82** by hydraulic fluid **85**, which is also in communication with housing **81**. As housing **81** is driven in a reciprocal motion, which could involve a vibration, for example, its movement is transmitted by hydraulic fluid **85** to move responsive element **84** co-reciprocally with housing **81**. Vent **86** accommodates movement of housing **81** relative to rod **87** connected to piston **82** and anchor point **83**. The speed and stroke length of movement of responsive element **84** can differ from the speed and stroke length of reciprocally driven housing **81** to achieve a variety of purposes such as power output, dynamic balance, shock absorption, or vibrational dampening. The movement imparted to responsive element **84** by movement of housing **81** can be coupled to other elements by mechanical, electrical, or hydraulic coupling systems such as described above for counter-reciprocating embodiments.

Many other variations on co-reciprocating systems are also possible. For example, power can be input to an element moveable within a housing, such as element **84** so that a housing, such as housing **81**, moves responsively by a hydraulic coupling, such as coupling **85**. An unmoved element, such as piston **82**, can complete the hydraulic coupling between the reciprocating elements and can serve as a reference for the other movements. A vibration dampening system can use the vibration to be damped as a drive force reciprocating one element that is hydraulically coupled to another so that the vibrational motion is transmitted to a responsive mass moving reciprocally at a velocity and direction that dampens the original vibration relative to a fixed mount. Once the hydraulic coupling between unmoved, driven, and responsive elements is understood, a multitude of variations of such an arrangement become available to meet a corresponding multitude of needs for reciprocal movements.

I claim:

1. A reciprocating system comprising three elements interrelated so that:

a. one of the elements is a housing containing hydraulic fluid serving as a hydraulic coupling;

b. two of the elements are arranged within the housing in communication with the hydraulic coupling;

c. one of the elements is fixed and two of the elements are movable;

d. one of the movable elements is a driven element moved in a driven reciprocal motion;

e. another of the movable elements is a responsive element moved in a responsive reciprocal motion;

f. the hydraulic coupling transmits movement from the driven element to cause the responsive element to move in the responsive reciprocal motion; and

g. the driven and responsive reciprocal motions are coaxial.

2. The system of claim **1** wherein the responsive reciprocal motion is counter to the driven reciprocal motion.

3. The system of claim **1** wherein the driven and responsive reciprocal motions differ in stroke and velocity.

4. The system of claim **1** wherein the responsive reciprocal motion has an unvarying phase relation to the driven reciprocal motion.

5. The system of claim **1** wherein energy stored in the responsive element is returned to the driven element during a predetermined portion of the driven reciprocal motion.

6. The system of claim **1** wherein the hydraulic coupling divides momentum between the driven and responsive elements.

7. The system of claim **1** wherein a resilient system biases movement of one of the reciprocating elements in one direction.

8. The system of claim **1** wherein power is output from the responsive element.

9. The system of claim **1** wherein a wall is arranged between an inner and an outer one of the moving elements.

10. The system of claim **1** wherein the driven element includes a piston of an internal combustion engine, and the responsive element receives a power input for moving the piston to start the engine.

11. The system of claim **1** wherein the driven and responsive reciprocal motions do not substantially move the center of gravity of the system.

12. The system of claim **1** wherein the hydraulic coupling transits both directions of driven reciprocal motion to the responsive element.

13. The system of claim **1** wherein the hydraulic fluid is divided into two volumes arranged at opposite end regions of reciprocating strokes of the reciprocating elements.

14. The system of claim **1** wherein power is output from the responsive element.

15. The system of claim **1** wherein the driven element is the housing.

16. The reciprocating system for a driven element moved in a driven reciprocating motion, the reciprocating system comprising:

a. hydraulic fluid arranged in communication with opposite end regions of the driven reciprocating element;

b. a responsive element having opposite end regions arranged in communication with the hydraulic fluid; and

c. reciprocating motion of the driven element is transmitted via the hydraulic fluid to move the responsive element in a responsively reciprocating motion in an unvarying phase relation to the driven reciprocating motion.

17. The system of claim **16** wherein power output is derived form the responsive element.

18. The system of claim **16** wherein the driven element and the responsive element are arranged for moving coaxially.

19. The system of claim **16** wherein the driven element and the responsive element are arranged for moving coaxially within a housing containing the hydraulic fluid so that the driven and responsive reciprocal motions do not substantially move the center of gravity of the system.

20. The system of claim **16** wherein the hydraulic fluid changes shape during movement of the driven element and the responsive element.

21. The system of claim **16** wherein the hydraulic fluid transits both reciprocating strokes of the driven element to the responsive element, and power output is derived from the responsive element.

22. The system of claim **21** wherein momentum is divided between the driven element and the responsive element.

23. The system of claim **19** wherein the driven element and the responsive element are separated by a wall.

24. The system of claim **22** wherein energy stored in the responsive element is returned tot he driven element during a predetermined portion of the driven reciprocating motion.

25. The system of claim **16** wherein a resilient system biases one of the reciprocating elements in a predetermined direction.

26. The system of claim **16** wherein the driven element is formed as a housing contained the hydraulic fluid and the responsive element.

27. The system of claim **26** wherein the responsive element moves co-reciprocally with the housing.

28. The system of claim **16** wherein the responsive reciprocating motion is counter to the driven reciprocating motion.

29. The system of claim **16** wherein the driven and responsive reciprocating motions differ in velocity and stroke.

30. The system of claim **16** wherein the hydraulic fluid is contained one of the reciprocating elements.

31. The system of claim **16** wherein the driven and responsive reciprocal motions do not substantially move the center of gravity of the system.

32. A reciprocating system comprising:

a. three interrelated elements that include a driven element moved in a reciprocal motion, a responsive element moved in a responsive reciprocal motion, and an unmoved element;

b. a hydraulic coupling that transits motion of the driven element to the responsive element to cause the responsive element to move in the responsive reciprocal motion so that a portion of the energy delivered to the driven element is transferred to and temporarily stored in the responsive element;

c. the hydraulic coupling being confined within a housing that constitutes one of the elements; and

d. the driven and responsive reciprocal motions are coaxial.

33. The system of claim **32** wherein the driven element is the housing, and the responsive element moves co-reciprocally with the housing.

34. The system of claim **33** wherein the hydraulic coupling gives the co-reciprocal motion of the responsive element a velocity and stroke different from the velocity and stroke of the housing motion.

35. The system of claim **32** wherein the responsive element and the driven element are arranged with in the housing and move counter-reciprocally relative to each other.

36. The system of claim **35** wherein the stroke lengths and velocities of the counter-reciprocating elements differ from each other.

37. The system of claim **32** wherein the energy temporarily stored in the responsive element is returned to the driven element during a predetermined portion of the driven reciprocal motion.

38. The system of claim **32** wherein the driven element and the unmoved element are arranged within the housing, and the housing moves co-reciprocally with the driven element.

39. The system of claim **38** wherein the hydraulic coupling gives the co-reciprocal motion of the housing a velocity and stroke different from the velocity and stroke of the driven element.

40. The system of claim **32** wherein the hydraulic coupling divides momentum between the driven and responsive element and transits both directions of the driven reciprocal motion to the responsive element.

41. The system of claim **32** wherein power is output from the responsive element.

42. The system of claim **32** wherein the driven and responsive reciprocal motions do not substantially move the center of gravity of the system.

43. The system of claim **32** wherein the hydraulic fluid is contained at each end region of the reciprocating strokes of the elements.

44. The system of claim **43** wherein the driven and responsive elements are separated by a wall and do not substantially move the center of gravity of the system.

45. The system of claim **32** wherein the responsive reciprocal motion has an unvarying phase relation to the driven reciprocal motion.

* * * * *